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EFFICIENCY TESTS OF A GAS OVEN

A Thesis submitted to
The Faculty of the Towne Scientific School
of
The University of Pennsylvania
for the
Degree of Bachelor of Science
in
Mechanical Engineering
by
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William J. Mack
June 1926

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Chapter 1.

INTRODUCTION

1. Purpose of the Investigation.

The primary object of this investigation was to determine the efficiency of a domestic gas oven and ascertain a method of testing by which different ovens could be compared, and their relative merits fixed in a definite and conclusive manner.

At present manufacturers test ovens by the practical but haphazard means of baking a pan of biscuits. The time taken to bake throughly is taken as an index of the ovens worth. If the biscuits were always of the same composition and texture this method would be fairly good. However, it is not possible to fulfill these conditions. The humidity also affects the rate of baking. Also there is no precise method of determining when the baking is just completed, so this procedure is open to crieicism. The results obtained are so indefinite as to mean little, and are worthless as an index of oven performance.

While the baking test would give an indication of the performance of two or three ovens tested simultaneously, it could not be used to compare the performance of ovens in Philadelphia and New York, due to the impossibility of correcting for all the variables involved.

Chapter 2.

Description of Apparatus

1. Coil Test.

The apparatus used in this test consisted of a coil, containing 22 feet of $\frac{3}{8}$ inch copper tubing, providing 2.25 square feet of heating surface. This was connected to the water line through a $\frac{1}{8}$ inch regulating valve and discharged through a thermometer well to the weighing bucket. The water entered from the top, flowed to the bottom of the coil, and then upward through the coil. A thermometer well placed in the line near the entrance to the coil was used to determine the initial temperature of the water.

The oven temperature was observed by means of a 500 degree thermometer.

2. Asbestos Loaf Test.

The apparatus used in this part of the investigation consisted of a loaf of asbestos, made up of two pounds of dry asbestos and enough water to give a consistency easily moulded. This was put in a tin pan and baked in the usual manner.

Thermo-couples were used to determine the temperatures at two points in the oven and in the center of the loaf.

3. Evaporation Test

The apparatus used consisted of the baking pan used in the asbestos loaf test, one 500 degree thermometer and one 220 degree thermometer.

In all tests the gas consumed was measured by a five light meter, the gas pressure being determined by a water manometer, and its temperature by a 220 degree thermometer. All determinations of weight were made using a scale weighing to the nearest quarter ounce.

Chapter 3.

Description of the Preparation for the Test, and of the Actual Conduct of the Test.

1. Preparation and Conduct for Coil Test.

For this test the copper tubing was shaped into a circular coil about a foot in diameter. The ends of the coil were passed through the top of the oven and connections made so that the water flowed up through the coil. The coil surface was not changed, but as the test went on the natural bright finish oxidized, turning a dark brown color. The coil was connected by means of a regulating valve to the water system, and discharged into a weighing bucket.

The test was started by lighting the oven and adjusting the water flow. After the oven temperature and the temperature rise of the water were constant, the run was started. One hour runs were made, supplemented by a few half hour ones as a check.

2. Preparation and Conduct of Asbestos Loaf Test.

Three thermo-couples were inserted through holes drilled in the oven walls. One was placed at the side of the oven, another at the top, and the third in the middle of the loaf. The loaf was throughly mixed before each run, and enough water added to give it the proper consistency.

While the oven was being heated, the loaf was weighed, and its initial temperature recorded. After oven conditions became constant, the loaf was inserted

and the run started. The runs lasted one hour, readings being taken every five minutes. The temperatures were taken as milli-volts, and converted into degrees Fah. using the calibration curves for the couples. At the end of the run the loaf was removed from the oven and weighed. This weight subtracted from the original weight gave the amount of water evaporated.

3. Preparation and Conduct of the Evaporation Test.

The pan used in the asbestos loaf test was cleaned, and after being half filled with water, was placed in the heated oven. After an hours run the pan was removed from the oven and weighed again. The oven temperature was observed in order to find the degree of superheat in the steam formed. The barometer was read in order to determine the steam pressure.

Chapter 4

Computations and Typical Calculations

Computations - Coil Test

Note: The correction for the heating value of the gas applies to all tests.

Notation:

Let W = net weight of water heated, in pounds.

t_1 = temperature of the cold water, °F.

t_2 = Temperature to which water is heated, °F.

Q = cubic feet of gas as metered

Q' = cubic feet of gas at standard conditions of 29.92" Hg and 60°F.

t_3 = temperature of the gas, °F.

P = barometric pressurs, "Hg

p = gas pressure, "water.

Assume heating value of the gas = 530 B.T.U. per cu. ft. at standard conditions. This is the legal value, and closely agrees with the values found by various experimenters in the Mechanical Laboratory, using the Junker Calorimeter.

$$\text{Then } Q' = Q\left(\frac{520}{460 + t_3} \times \frac{P + \frac{p}{13.6}}{29.92}\right)$$

and the efficiency of the coil $\dfrac{W(t_2 - t_1)}{Q' \times 530}$

Sample Calculations

Coil Test

Gas used-6.27 cu.ft., at 4.4" water, 70°F, barom. 30.62"

B.T.U. content of gas as metered

$$530 \times \frac{520}{530} \times \frac{30.62 - \frac{4.4}{13.6}}{29.92}$$

=539 B.T.U. per cf. as metered.

Total Heat Supplied = 539 x 6.27 = 3380 B.T.U.

Temp. rise of water = 23.6°F

W = 28.5#

Total heat absorbed by the water

28.5 x 23.6 = 672 B.T.U.

Efficiency = $\frac{672}{3380}$ = 19.9%

Time of run - 30 minutes

Gas flow = 2 x 6.27 = 12.54 cf. per hour, as metered.

Sample Calculation

Asbestos Loaf Test

Time: 2 hours Total gas used 93.5 cf. at 3.9"water and 82°

Barometer - 30.12 Wt. of dry asbestos = 2.00#

Wt. of water heated = 2.312#
Wt. of water evaporated = 1.906 #
Specific heat of asbestos = 0.32

Specific heat of sheet iron pan = 0.127 Oven temp. = 550°F

Degrees superheat of steam = 550 - 212 = 338°F

Initial temp. of loaf = 70°F

Total heat supplied by the gas = 517 x 93.5 = 48300 B.T.U.

And heat absorbed by the water

2.312 x (212--70) = 560 B.T.U.

Heat absorbed by steam
1.906 x (1310--180) = 2165 B.T.U.

Heat absorbed by asbestos
2.00 x 0.32 x (550--70) = 307 B.T.U.

Heat absorbed by sheet iron pan
1.25 x 0.127 x (550--70) = 76 B.T.U.

Total heat absorbed = 3108 B.T.U.

Efficiency $\frac{3108}{48300}$ = 0.[illegible]

Sample Calculations

Evaporation Test

Note: This is the same as the asbestos loss calculation, except for the heat added to the asbestos. Obviously this is equal to zero.

Chapter 4.

Tabulation of Summarized Data and Results. Curves.

COIL TEST DATA

Q'	[illegible]	t_1	t_2	t_3	[illegible]	P "H_2O	P "Hg	Oven Temp.
48.0	16.7	68	142	[illegible]	[illegible]7.91	4.4	30.62	-----
9.45	19.0	63	158	70	40.00	4.3	29.81	443
3.83	21.2	63	106	70	40.00	4.3	29.81	412
4.26	23.[illegible]	63	11[illegible]	70	40.00	4.3	29.81	408
1.89	24.0	63	87	70	40.00	4.3	29.81	431
11.7	24.[illegible]	68	10[illegible]	70	40.00	4.1	29.[illegible]	[illegible]10
17.7	22.0	68	120	75	40.00	4.1	29.[illegible]	300
31.3	20.2	68	153	70	40.00	4.1	30.[illegible]	360
44.8	17.6	68	163.4	66	43.00	4.1	29.53	453
49.[illegible]	19.[illegible]	67	145.[illegible]	66	40.00	4.1	29.[illegible]6	[illegible]70
16.2	20.5	66	106	66	44.00	4.1	29.53	270
6.55	22.6	68	85	66	40.00	4.2	29.50	191
46.6	21.7	62	150	62	60.00	4.1	30.3[illegible]	450

Time of all runs - one hour

ASBESTOS LOAF DATA

Run number	1	2	3	4
Oven temp.	550	400	380	310
Wt. of water heated	2.31	2.31	2,31	2.31
Wt. of water evaporated	1,906	0.59	0.31	0.16
Gas temp.	82	78	76	77
Gas pressure	3.9	4.2	4.5	4.4
Cu. Ft. of gas as metered	93.5	23.5	28.4	14.5
Wt. of asbestos heated	2.00	2.00	2.00	2.00
Total heat supplied	4[illegible]300	12100	14700	7520
Total heat absorbed	3160	1o30	1192	674
Per cent effiviency	[illegible].55	8.5	8.1	8.9
Time of runs, hours	2.0	1.0	1.0	1.0
Orig. temp. of loaf, °F.	70	72	75	75
Barometer	30.12	30.03	30.08	30.08

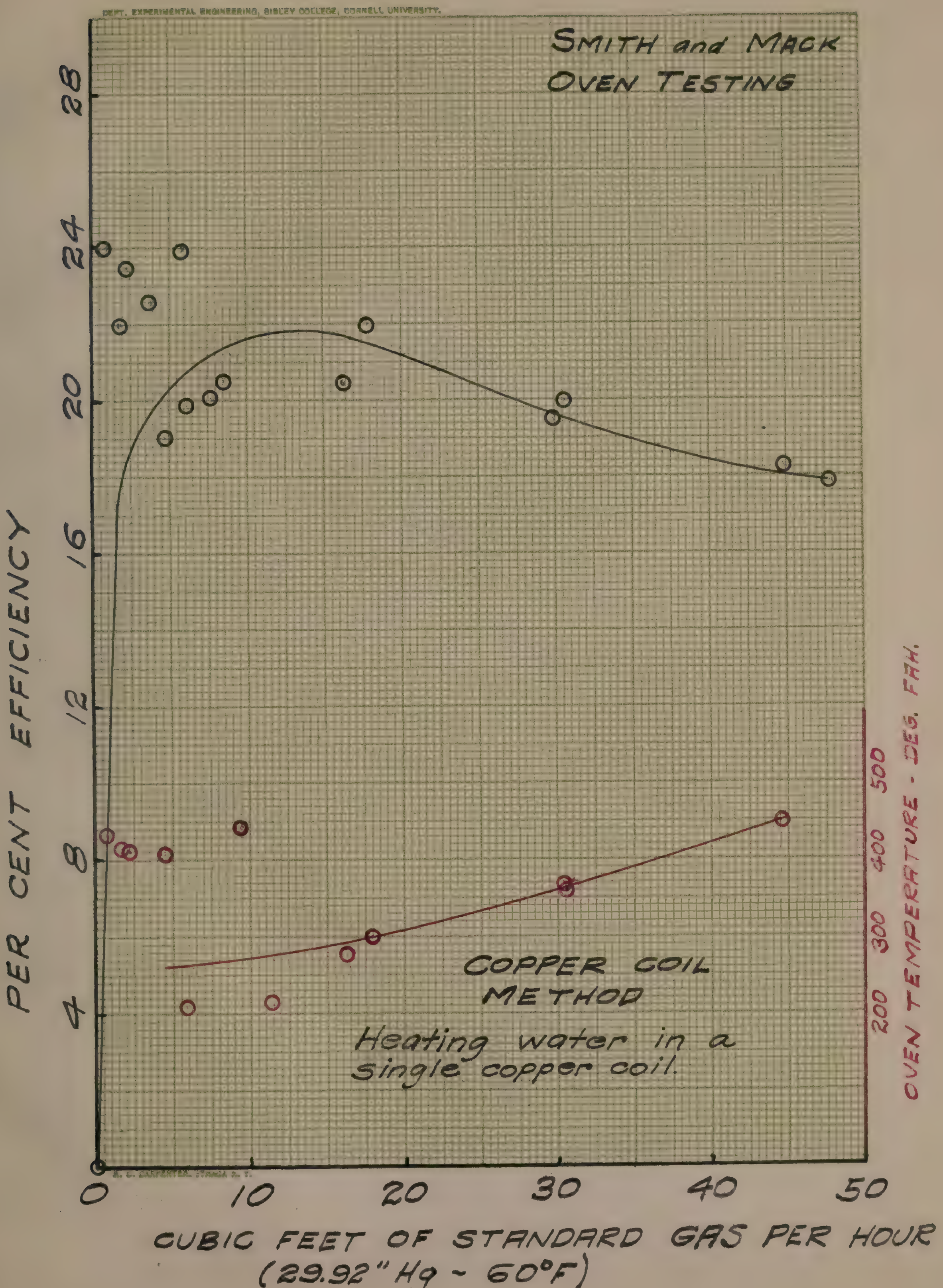
While some of the data given above is not of major importance, it fully describes test conditions.

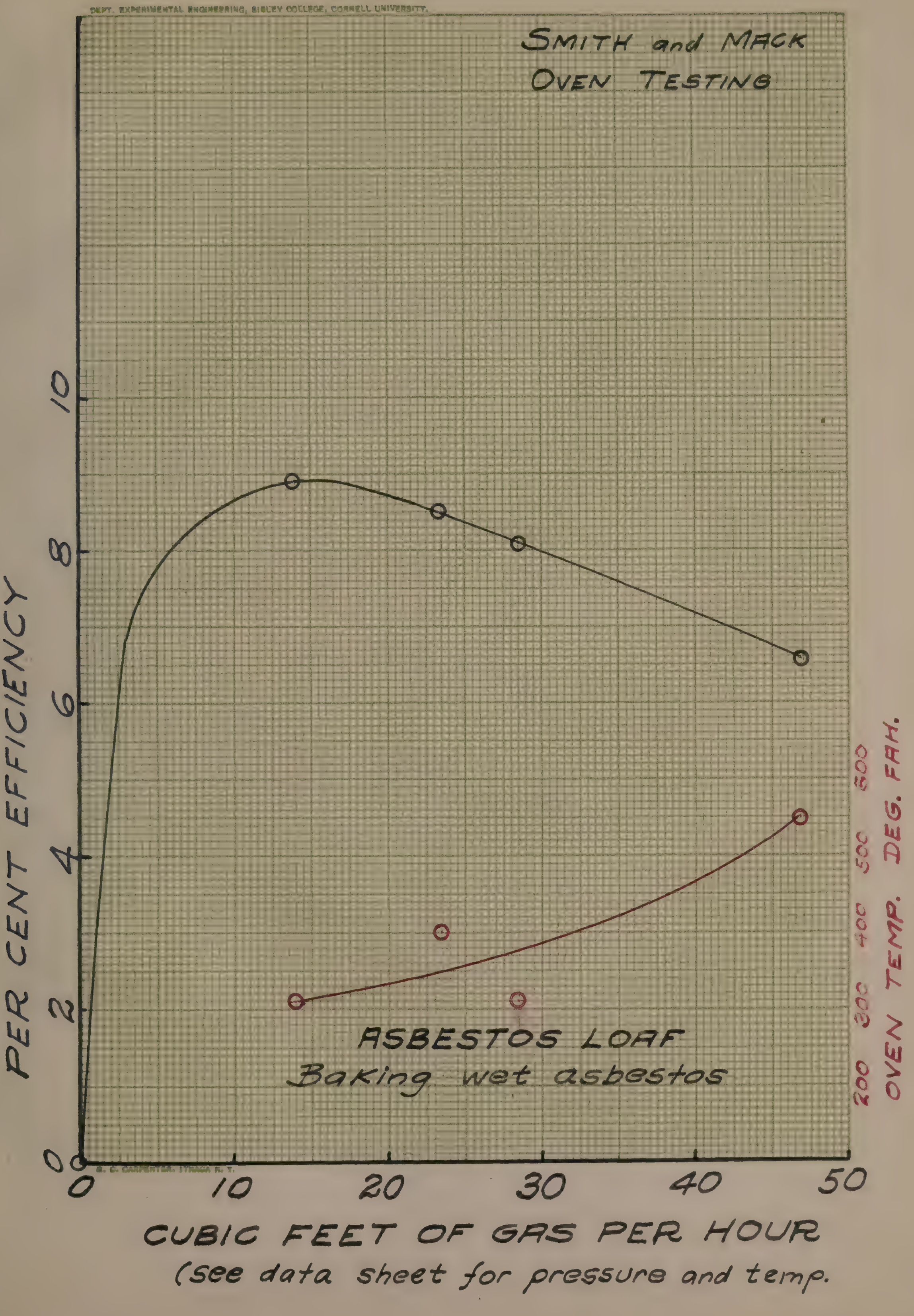
EVAPORATION TEST DATA

OPEN PAN METHOD

Run number	1	2	3	4	5
Cu. ft. of gas, as metered	48.0	27.4	14.13	9.20	[illegible]
Weight of water heated	1.75	1.75	1.75	1.75	1.75
Weight of water evaporated	1.44	0.94	0.44	0.19	[illegible]
Total heat supplied	24700	14100	7300	4740	14000
Total heat absorbed	1895	1290	747	477	[illegible]
Per cent efficiency	7.7	9.2	10.2	10.05	8.5
Gas pressure	4.5	4.5	4.5	4.5	4.5
Gas temperature	74	75	75	74	75
Oven temperature	490	400	355	300	410

Barometer - 29.85
Wt. of pan - 1.25
Time of runs - 1 hour


DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.
SMITH and MACK
OVEN TESTING
PER CENT EFFICIENCY
28
24
20
16
12
8
4
0
COPPER COIL
METHOD
Heating water in a single copper coil.
OVEN TEMPERATURE - DEG. FAH.
200
300
400
500
E. C. CARPENTER, ITHACA N. Y.
0
10
20
30
40
50
CUBIC FEET OF STANDARD GAS PER HOUR
(29.92" Hg - 60°F)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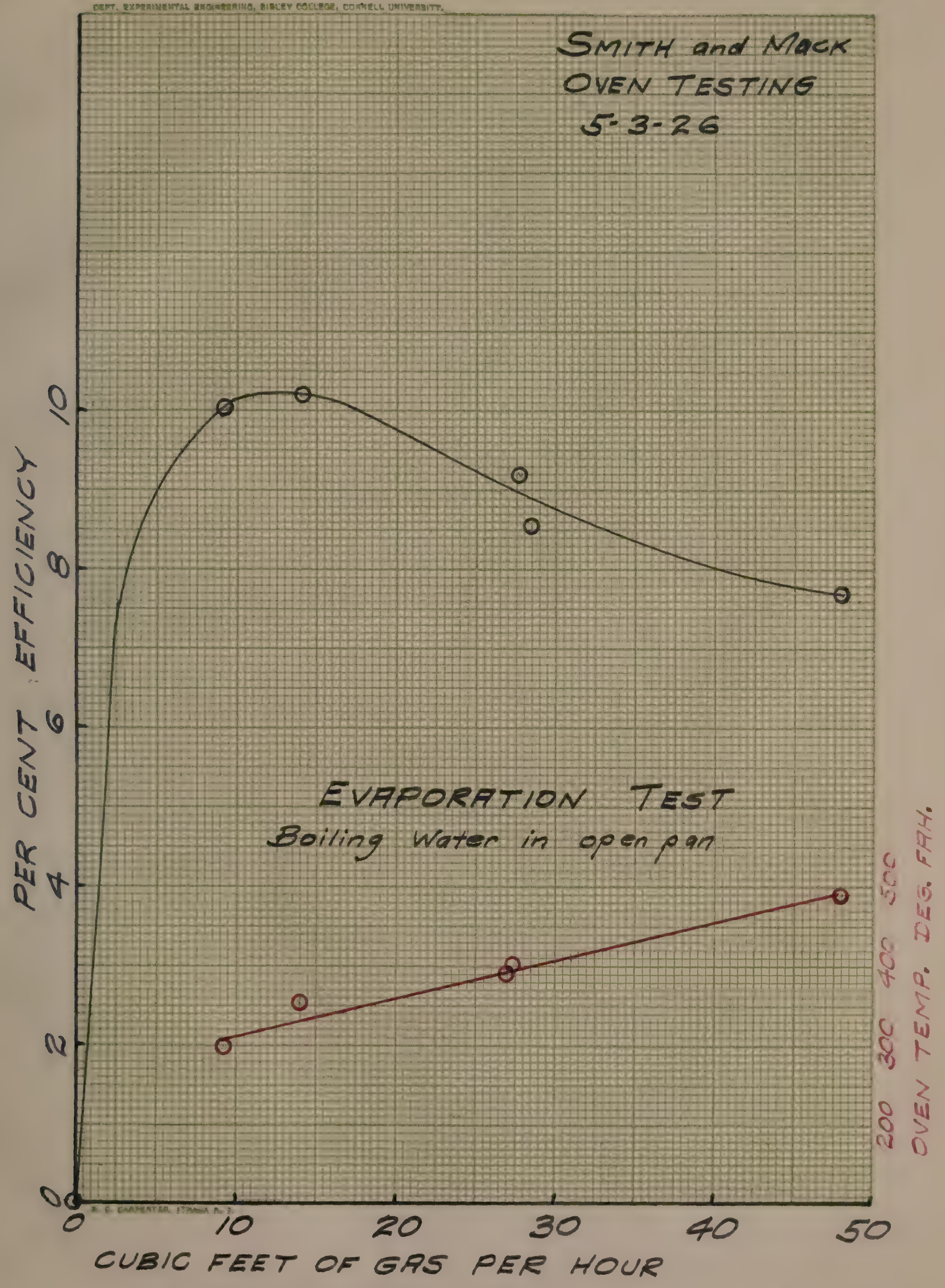
SMITH and MACK
OVEN TESTING
PER CENT EFFICIENCY
0
2
4
6
8
10
0
0
10
20
30
40
50
OVEN TEMP. DEG. FAH.
200
300
400
500
600
ASBESTOS LOAF
Baking wet asbestos
E. C. CARPENTER, ITHACA N. Y.
CUBIC FEET OF GAS PER HOUR
(see data sheet for pressure and temp.



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OVEN TESTING
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EVAPORATION TEST
Boiling Water in open pan

4.5" H_2O 80°F Barometer 29.85"

Chapter 6.

Discussion and Conclusions.

a. Accuracy of Methods and Results.

In this work, the methods used were of the greatest importance. No attempy was made to work exactly, as this would seriously curtail the scope of the investigation, due to the greater time required.

The heating value of the gas was assumed equal to 530 B.T.U. per cubic foot, at 29.92"Hg, and 60°F: and the gas meter was assumed to read correctly. As the same gas supply and meter were used throughout the entire test, this error was negligible in comparing methods.

The increase in room temperature, from about 50 to 80 degrees during the term, caused a variable loss of heat by radiation. The opening and closing of doors and windows caused a variable convection loss. About the middle of the term the 500 degree Fah. thermometer, used to measure oven temperatures, was broken, so it was replaced by a 1000 deg. one.

Gas and water pressures varied slightly during the runs, but readings were taken at five minute intervals, and the mean values used in the calculations.

It was hard to accurately measure the degree of superheat in the steam formed, as the temperature of the oven gradually increased during the runs. Briefly, the accuracy of the tests was great enough to compare the three methods used, which was the object of this thesis.

Conclusions.

The coil method is not adapted to oven testing, as the results are unreliable. The coil maintains a constant temp. below $212^{\circ}F$, and thus puts a constant load on the oven which is far different from a baking load. The location, size and type of coil greatly affect the efficiency, as shown by comparing these tests with the tests of Earp and Dodson, of the class of 1925.

The asbestos loaf method is the best of the three methods compared. It accurately and closely imitates baking conditions, absorbing a variable amount of heat during the run. The thermo-couples embedded in the loaf showed a rise in temperature up to about 212°, then a constant temperature of 212°, until the loaf dried in as far as the couple, then a further rise in temperature.

The open pan method, using straight evaporation. gave fairly good results. The efficiency curve for the open pan method is roughly similar to the curve for the asbestos loaf. However, the open pan method does not imitate or even approximate actual baking conditions, as the temperature of the water is never above $212^{\circ}F$.

Heat transfer is proportional to the temperature difference. This is shown by the efficiency curves. The coil had the lowest final temperature and the highest efficiency; and the asbestos loaf had thehighest final temp.

and the lowest efficiency.

The time temperature curve, in the appendix, gives the heating and cooling rates for the oven alone. Calibration curve for the thermo-couples also in the appendix.

Chapter 7.

Recommendations for Future Tests.

The testing of gas ovens is capable of great development. At present there is no scientific method of testing.

The asbestos loaf method is worthy of a careful trial. It would be desirable to use the Junker Calorimeter at the same time the run was being made, thus giving a more accurate determination of the heating value of the gas. The gas meter should be checked on a meter prover before and after each run. Runs should be from one to two hours, to reduce error due to opening oven door to a minimum. The humidity should be observed during each run, and the actual evaporation corrected for it.

If possible the oven should be protected from air currents by shielding it with a screen or canvas. The low efficiency of the oven at baking temperatures shows the need for better insulation of ovens. A comparitive run could be made with and without insulation, and the improved efficiency determined. Also runs could be made with varying amounts of insulation, and the most economical thickness determined.

Chapter 3.

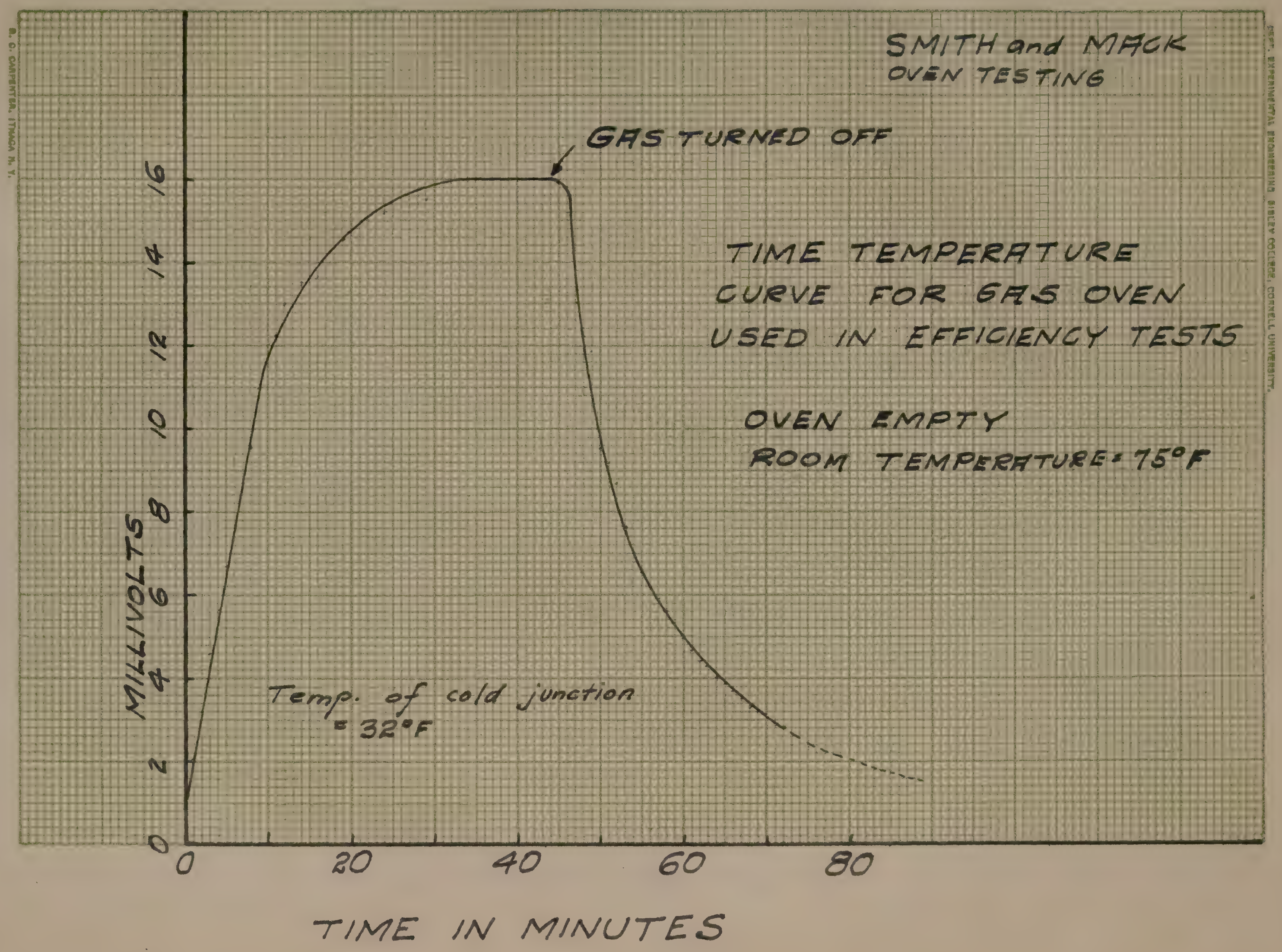
Bibliography

The following books were used for reference:

Tests of a Gas Stove-----Purves and Chumney----1924
Gas Range Tests------- Earp and Dodson----------1925

Appendix

DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.



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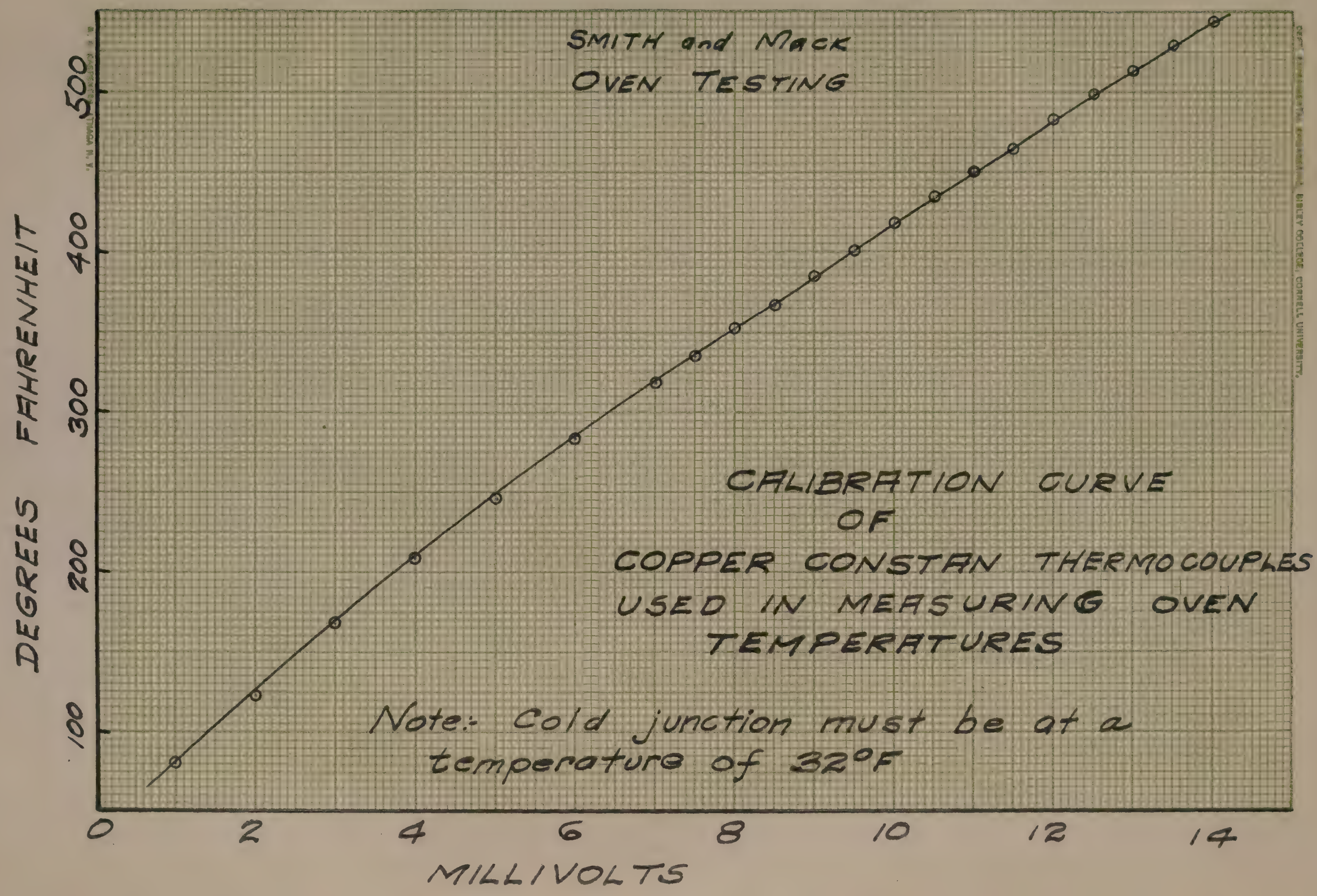

SMITH and Mack
OVEN TESTING

CALIBRATION CURVE
OF
COPPER CONSTAN THERMOCOUPLES
USED IN MEASURING OVEN
TEMPERATURES

Note:- Cold junction must be at a temperature of 32°F

Calculation for the Mean Specific Heat of Asbestos.

Asbestos is represented by the formula

$H_4Mg_3Si_2O_9$ which is composed of

$(SiO_2)_2$ $(MgO)_3$ $(H_2O)_2$

Then finding the various parts by weight

$(SiO_2)_2$	2(28 32)	120	$\frac{120}{276}$	43.5% by wt.
$(MgO)_3$	3(24 16)	120		43.5%
$(H_2O)_2$	2(2 16)	36		13,0%
		276		100.0%

Prof. J.W.Richards, in his book " Metallurgical Calculations, Vol. I", gives the following values for specific heats:

SiO_2	0.1833
MgO	0.2420
H_2O	1.000

Therefore the mean specific heat of asbestos equals

$$\begin{array}{ll} 0.435 \times 0.1833 & 0.0798 \\ 0.435 \times 0.2420 & 0.1052 \\ 0.130 \times 1.000 & \underline{0.1300} \\ & \underline{0.3150} \end{array}$$

As no allowance was made for the increase of specific heat with temperature, the mean specific heat of asbestos may be taken as 0.32

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Efficiency tests of a gas oven.

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